SPECTRUM ANALYTICAL, INC.

FEATURING

HANIBAL TECHNOLOGY

Treatability Report

Site Location:

Chevron – CMS - Main Yard

Perth Amboy, NJ

Presented to:

URS Corporation

By:

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1.0 Introduction

Spectrum Analytical, Inc. (SA) has evaluated the effectiveness of Conventional Fenton's Reagent (CFR), catalyzed sodium persulfate, and RegenOx™ chemical oxidation technologies that may be used at this site. The contaminants of concern (COCs) are benzene and benzo(a)pyrene and these are present in the soil. Two soil samples were submitted to be tested.

These in-situ chemical oxidation technologies involve injecting a solution of oxidant into the subsurface and mineralizing the target contaminants. Once injected into the subsurface and consumed by combined effect of mineralizing target contaminants and satisfying soil oxidant demand (SOD) due to reduced conditions and/or high background natural organic matter, hydrogen peroxide and sodium persulfate yield benign end products. The by-products of H_2O_2 (HP) decomposition under typical field conditions are water and oxygen while sodium persulfate decomposition yields benign end products such as sodium sulfate, a *water soluble, harmless, non-toxic material*. RegenOx™ is a two part product with Part A being the oxidizer powder and Part B being the liquid activator. Part A contains a mixture of sodium percarbonate, sodium carbonate, sodium silica, and silica gel. Part B contains a mixture of sodium silicate solution, silica gel, and ferrous sulfate.

A protocol has been developed by Spectrum Analytical to assess the efficacy of use of oxidation technologies at sites. This procedure, which was used at this site, consisted of obtaining data from technology screening tests that evaluated the effectiveness of chemical oxidation technologies (CFR, iron catalyzed persulfate and the RegenOx™ process) in mineralizing target COCs. The results of these tests can be used to determine the optimal conditions for the complete in situ mineralization of the COCs found in the subsurface at the site using the oxidant to desired concentrations.

The following approach was proposed:

- Homogenize and characterize the two site soils.
- Determine the inherent oxidant demand of the native soil and groundwater for each oxidant.

- Assess the degradation of the COCs in a soil/ DI water matrix with each oxidant.
- Investigate the influence of reaction parameters such as concentration on COCs degradation and determine treatment efficiency and dosage for use in column experiments.
- Set up column experiments to mimic actual field conditions.

2.0 Experimental Section

2.1 Sampling of Site Samples

The site soil samples were received on March 7, 2008 on ice at 5 ^{o}C. The first sample was labeled S2249RG2 and was collected on March 5 at 12:15 p.m. The second sample was labeled S1016RC1 and was collected on March 5 at 2:45 p.m. Each soil was contained in 5 soil cores 20 inches long and 1.5 inches wide. After the receipt of the site samples and following SA's sample log-in procedure, all samples were stored in a refrigerator maintained at 4 °C.

2.2 Preparation and Characterization of Site Samples

In order to ensure a known uniform source of soil for the tests, the submitted soil samples were homogenized and characterized prior to use.

Composite Site Soil. Each soil was treated similarly. One randomly chosen core from each sample was set aside intact to be used in the column tests. The other four cores were emptied, one at a time, into a plastic bag and mixed. All work was done in a plastic bag to reduce the chance of losing volatile organic compounds (VOCs). Rocks were removed and clumps of soil were broken up. Each soil was mixed thoroughly with the soil from the other cores. The soil labeled S2249RG2, which we will refer to as Soil 1, was found to be dark, wet clay with rocks and fibers. It had a gasoline odor. The soil labeled S1016RC1, which we will refer to as Soil 2, was found to be dark soil with orange streaks, wet, and containing some clay and many pieces of gravel. It also had a gasoline odor.

Samples of each homogenized soil were submitted to the lab for testing. The soils were tested in duplicate for VOCs, semi-volatile organic compounds (SVOCs), TCLP benzene, TCLP lead, total lead, tetraethyl lead, pH, total organic carbon (TOC), and grain size.

2.3 Soil Oxidant Demand and Degradation of COCs Using CFR (Task 1)

The soil oxidant demand (SOD) of each site soil for CFR was determined using a series of jar experiments at two oxidant concentrations under a groundwater/dry soil ratio of 5:1 (by weight) at 20 °C. These sets of experiments were also used to investigate the ability of CFR to oxidize the COCs in a soil/DI water matrix. All samples were measured for the oxidant level, COCs, pH, conductivity, and ORP at 2, 4, and 24 hours. Consumption of the oxidant (at two oxidant concentrations) by the soil was determined for each test time. Solutions of 15 and 25 % hydrogen peroxide with ferrous sulfate and low pH were used. Each batch had two control experiments included, one with only soil and DI water at low pH and the other with DI water and oxidant to determine the amount of auto-decomposition.

All tests were conducted using a series of 250-mL amber glass jar or 60-mL clear glass vial reactors placed on a round-motion shaker system used to enhance the contact and mass transfer of the oxidant with soils. The shaker system was operated under a constant shaking speed of 80 rpm. The reaction temperature was 20 °C and was controlled using an incubator. Detailed experimental conditions for the determination of the oxidant demand of each site soil are given in Table 1.

The procedure for the oxidant demand tests involved oxidizing each composite soil with oxidant solutions at a 5:1 water to dry soil ratio. The soil was weighed into the reactors and the correct amount of ferrous sulfate was added to be 5 g/L in the 15% peroxide experiments and 9 g/L in the 25% peroxide experiments. Then the appropriate solution was added in small aliquots very slowly until there was zero-headspace. Each solution was made by diluting hydrogen peroxide with DI water and using phosphoric acid to lower the pH to 3. Due to the high concentrations of peroxide used, 15 and 25 %, with the ferrous sulfate there was a tremendous reaction when added to the soil. The solutions had to be added very slowly to prevent loss by bubbling over. Tedlar bags were attached to all containers to collect the gas. At each test time, the reactors were removed from the incubator and allowed to settle before samples were collected using a disposable syringe. Samples of the water were submitted for VOC, SVOC, and dissolved oxygen (DO) testing. After all of the liquid was removed, the soil was also submitted for VOC and SVOC testing. About 10 mL of each aqueous sample was filtered using 0.45-μm syringe filters for pH, ORP, conductivity, and peroxide. The peroxide concentration is found by performing a titration on an aliquot of the sample that has been acidified using potassium permanganate as the titrant. After the end point is reached, the amount of titrant used is recorded. The amount of titrant is compared to a similarly prepared calibration curve to determine the result.

Consumption of the oxidant by the composite site soil was determined at each test time. The soil SOD was determined using equation 1:

$$SOD = V(C_0 - C_s)/m_{soil} \qquad \text{(g/kg)} \qquad (1)$$

where V = the total volume in L of oxidant solution in the reactor; C_0 = initial oxidant concentration in g/L; C_s = the oxidant concentration in g/L at each reaction period; m_{soil} = the mass in kg of dry soil used in the reaction.

2.4 Soil Oxidant Demand and Degradation of COCs Using Iron Catalyzed Persulfate (Task 2)

The soil oxidant demand (SOD) of each site soil for iron [Fe(II)] catalyzed persulfate was determined using a series of jar experiments at two oxidant concentrations under a groundwater/dry soil ratio of 5:1 (by weight) at 20 °C. These sets of experiments were also used to investigate the ability of iron catalyzed persulfate to oxidize the COCs in a soil/DI water matrix. All samples were measured for the oxidant level, COCs, pH, conductivity, and ORP on days 1, 4, and 10. Consumption of the oxidant (at two oxidant concentrations) by the soil was determined for each test time. Solutions of 20 g/L persulfate with 300 mg/L of iron [Fe(II)] and 40 g/L persulfate with 400 mg/L of iron Fe(II) were used. Each batch had two control experiments included, one with only soil and DI water and the other with DI water and oxidant to determine the amount of auto-decomposition.

All tests were conducted using a series of 250-mL amber glass jar or 60-mL clear glass vial reactors placed on a round-motion shaker system used to enhance the contact and mass transfer of the oxidant with soils. The shaker system was operated under a constant shaking speed of 80 rpm. The reaction temperature was 20 °C and was controlled using an incubator. Detailed experimental conditions for the determination of the oxidant demand of each site soil/groundwater are given in Table 2.

The procedure for the oxidant demand tests involved oxidizing each composite soil with oxidant solutions at a 5:1 water to dry soil ratio. The soil was weighed into the reactors and then the correct amount of the appropriate solution was added. Each solution was made by dissolving sodium persulfate and iron in the Fe(II) state in DI water. On each sampling day, the reactors were removed from the incubator and allowed to settle before samples were collected from each jar using a disposable syringe. Samples of the water were submitted for VOC, SVOC, and DO testing. After all of the liquid was removed, the soil was also submitted for VOC and SVOC testing. About 10 mL of each aqueous sample was filtered using 0.45-μm syringe filters for pH, ORP, conductivity, and persulfate. The persulfate concentration is found by treating a 1mL aliquot of the sample with acid and ferrous ammonium sulfate. After a timed period, ammonium thiocyanate is added to colorize the samples and they are read on the spectrophotometer at 450nm. The absorbance is compared to a similarly prepared calibration curve.

Consumption of the oxidant by the composite site soil was determined at each test day. The soil SOD was determined using equation 1 listed above in section 2.3.

2.5 Soil Oxidant Demand and Degradation of COCs Using RegenOx™ (Task 3)

The soil oxidant demand (SOD) of each site soil for RegenOx™ was determined using a series of jar experiments at two oxidant concentrations under a groundwater/dry soil ratio of 5:1 (by weight) at 20 °C. These sets of experiments were also used to investigate the ability of RegenOx™ to oxidize the COCs in a soil/DI water matrix. All samples were measured for the oxidant level, COCs, pH, conductivity, and ORP on days 1, 4, and 10. Consumption of the oxidant (at two oxidant concentrations) by the soil was determined for each test time. Solutions of 18 and 54 g/L RegenOx™ were used. Each batch had two control experiments included, one with only soil and DI water and the other with DI water and oxidant to determine the amount of auto-decomposition.

All tests were conducted using a series of 60-mL clear glass vial reactors placed on a round-motion shaker system used to enhance the contact and mass transfer of the oxidant with soils. The shaker system was operated under a constant shaking speed of 80 rpm. The reaction temperature was 20 °C and was controlled using an incubator. Detailed experimental conditions for the determination of the oxidant demand of each site soil/groundwater are given in Table 3.

The procedure for the oxidant demand tests involved oxidizing each composite soil with oxidant solutions at a 5:1 water to dry soil ratio. The soil was weighed into the reactors and then the correct amount of the appropriate solution was added. Each solution was made by dissolving sodium persulfate and iron in the Fe(II) state in DI water. On each sampling day, the reactors were removed from the incubator and allowed to settle before samples were collected from each jar using a disposable syringe. Samples of the water were submitted for VOC, SVOC, and DO testing. After all of the liquid was removed, the soil was also submitted for VOC and SVOC testing. About 10 mL of each aqueous sample was filtered using 0.45-µm syringe filters for pH, ORP, conductivity, and peroxide. The peroxide concentration is found by performing a titration on an aliquot of the sample that has been acidified using potassium permanganate as the titrant. After the end point is reached, the amount of titrant used is recorded. The amount of titrant is compared to a similarly prepared calibration curve to determine the result.

Consumption of the oxidant by the composite site soil was determined at each test day. The soil SOD was determined using equation 1 listed above in section 2.3.

2.6 Column Tests (Task 4)

Column tests were set up using the intact cores that were saved from the homogenization process. One treatment was selected for use in a 21-day column test. Each core of soil was cut down to have a six-inch long portion. This portion was subjected to a continuous flow of oxidant solution, 15 % hydrogen peroxide with 5 g/L of ferrous sulfate and a pH of 3, for 21 days. The effluent was collected and sampled on days 5, 14, and 21. A Tedlar bag was connected to the effluent container to collect any gas generated and this gas was tested on day 21.

3.0 Results and Discussion

The analytical instruments and methods used are summarized in Table 4.

3.1 Characterization of Site Samples

Characterization of Site Soil: The composite soils were tested in duplicate for VOCs, semi-volatile organic compounds (SVOCs), TCLP benzene, TCLP lead, total lead, tetraethyl lead, pH, total organic carbon (TOC), and grain size. The results are tabulated in Table 5.

Soil 1 had very high levels of gasoline components. The highest concentrations were benzene, 1,2,4-trimethylbenzene, and m,p-xylene, at concentrations that were over 100,000 µg/kg. The results for TCLP benzene were over 2,000 µg/L in both samples. In the semi-volatile analysis, the soil was found to be high in 1-methylnaphthalene, 2-methylnaphthlene, phenanthrene, pyrene, and fluorene. The total lead was found to be over 600 mg/kg while the TCLP lead was greater than 0.5 mg/L. The TOC was also high, with both samples at over 60,000 mg/kg. The grain size analysis indicates the soil is made up of fine, medium, and coarse sand as well as some silt.

Soil 2 had high levels of gasoline components as well. The compounds with the highest concentrations were 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, m,p-xylene, and n-propylbenzene which were greater than 10,000 µg/kg. The TCLP benzene was over 8 µg/L in both of the samples. In the semi-volatile analysis, the soil was found to be high in 1-methylnaphthalene and 2-methylnaphthlene. The total lead was found to be an average of 599 mg/kg while the TCLP lead was greater than 2 mg/L in both samples. The TOC was also high; both samples had concentrations greater than 40,000 mg/kg. The grain size analysis indicates the soil is made up of medium, coarse, and very coarse sand as well as some silt.

3.2 Soil Oxidant Demand and Degradation of COCs Using CFR (Task 1)

Four sets of experiments were used to determine the SOD of each soil for CFR and to investigate the degradation of COC's using CFR. Three solutions were used, one containing 15% peroxide and 4 g/L ferrous sulfate at a pH of 3 in DI water, the second containing 25% peroxide and 7.4 g/L ferrous sulfate at a pH of 3 in DI water, and the third being just DI water. All samples were analyzed at 2, 4, and 24 hours into the test for COC's, peroxide, pH, ORP, and conductivity. The SOD results are given in Tables 6 and 7. The degradation results are given in Tables 8 and 9.

Soil 1 had very high oxidant demand; the results were 781 g/kg in the 15% peroxide experiment and 1,303 g/kg in the 25% peroxide experiment at 24 hours. The result of the control experiment was 250 g/L, indicating that auto-decomposition of hydrogen peroxide is taking place (Experiments IC and ICd in Table 1 were performed with DI water, HP, and ferrous sulfate, and without soil). Over 99% of the peroxide in each experiment was gone within 24 hours. The pH of the samples stayed low for the duration of the test.

Soil 2 had very high oxidant demand; the results were 778 g/kg in the 15% peroxide experiment and 1,298 g/kg in the 25% peroxide experiment at 24 hours. The result of the control experiment was 250 g/L, indicating that auto-decomposition of hydrogen peroxide is taking place (Experiments IC and ICd in Table 1 were performed with DI water, HP, and ferrous sulfate, and without soil). Over 99% of the peroxide in each experiment was gone within 24 hours. The pH of the samples stayed low for the duration of the test.

The bench-test jar results for Soil 1 show that CFR performed the best in reducing the levels of benzene and total VOCs. The removal efficiency for benzene was 98% with both 15 and 25% hydrogen peroxide catalyzed with iron. The removal efficiency for total VOCs ranged from 87 to 88% with CFR. The results also show that CFR performed the best in reducing the levels of SVOCs including benzo(a)pyrene. The removal efficiency for benzo(a)pyrene was 53% and 44% with 15 and 25% CFR, respectively.

In both soil 1 and soil 2, increased levels of SVOCs were found in samples treated with CFR. This effect is likely due to the desorption of the contaminants from the soil from the peroxide treatment, making more contaminants extractable using the Method 8270 extraction method. Although more contaminants are released from the soil phase, the aqueous phase data indicates that the desorbed contaminants are oxidized in the aqueous phase.

Soil 2 testing showed significant decreases in the concentrations of the COCs in the treated samples as compared to the untreated samples. The bench-test jar results show that CFR performed the best in reducing the levels of benzene and total VOCs. The removal efficiency for benzene was 93% with both 15 and 25% hydrogen peroxide catalyzed with iron. The removal efficiency for total VOCs ranged from 77 to 73% with CFR.

3.3 Soil Oxidant Demand and Degradation of COCs Using Iron Catalyzed Persulfate (Task 2)

Four sets of experiments were used to determine the SOD of each soil for iron catalyzed persulfate and to investigate the degradation of COC's using iron catalyzed persulfate. Three solutions were used, one containing 20 g/L persulfate with 300 mg/L iron in DI water, the second containing 40 g/L persulfate with 400 mg/L iron in DI water, and the third being just DI water. All samples were analyzed at 1, 4, and 10 days into the test for COC's, persulfate, pH, ORP, and conductivity. The SOD results are given in Tables 10 and 11. The degradation results are given in Tables 12 and 13.

Soil 1 had moderately high oxidant demand, an average of 85.3 g/kg in the 20-g/L experiments and an average of 163 g/kg in the 40-g/L experiments on day 10. The results of the control experiments were also moderate at an average of 19.4 g/L indicating that some auto-decomposition of hydrogen peroxide is taking place (Experiments IIC and IICd in Table 2 were performed with DI water, persulfate and iron (II), and without soil). The pH of all the samples containing oxidant were low for the duration of the test due to the reaction of the persulfate.

Soil 2 had moderately high oxidant demand, an average of 69.5 g/kg in the 20-g/L experiments and an average of 106 g/kg in the 40-g/L experiments on day 10. The results of the control experiments were also moderate at an average of 18.4 g/L indicating that some auto-decomposition of hydrogen peroxide is taking place (Experiments IIC and IICd in Table 2 were performed with DI water, persulfate and iron (II), and without soil). The pH of all the samples with oxidant were low for the duration of the test due to the reaction of the persulfate.

The removal efficiency for benzene ranged from 57 to 83% with activated persulfate for Soil 1. The removal efficiency for SVOCs ranged from 86 to 88% with activated persulfate. The removal efficiency for benzo(a)pyrene for activated persulfate could not be calculated as the initial soil samples could not detect benzo(a)pyrene at a lower detection limit due to interferences. The initial soil samples were analyzed by Lancaster Laboratories.

Soil 2 showed a moderate decrease in COC concentrations. All compounds were much lower in the 40-g/L experiment soil than in the control soil. Results from the initial soil samples analyzed by Lancaster Laboratories were used to compare post-treatment results. The removal efficiency for benzene ranged from 62 to 67% with activated persulfate. The removal efficiency for total VOCs ranged from 2 to 48%. The removal efficiency for SVOCs was 46%. Benzo(a)pyrene was not detected above the method detection limit of 1,200 ug/Kg in the initial soil sample. Consequently, the removal efficiency of benzo(a)pyrene is not calculated.

3.4 Soil Oxidant Demand and Degradation of COCs Using RegenOx™ (Task 3)

Four sets of experiments were used to determine the SOD of each soil for RegenOx™ and to investigate the degradation of COC's using RegenOx™. Three solutions were used, one containing 18 g/L RegenOx™ in DI water, the second containing 54 g/L RegenOx™ in DI water, and the third being just DI water. All samples were analyzed at 1, 4, and 10 days into the test for COC's, persulfate, pH, ORP, and conductivity. The SOD results are given in Tables 14 and 15. The degradation results are given in Tables 16 and 17.

Soil 1 had high oxidant demand, an average of 92.5 g/kg in the 18-g/L experiments and an average of 281 g/kg in the 54-g/L experiments on day 10. The results of the control experiments were also moderate at an average of 53.3 g/L indicating that auto-decomposition of RegenOx™ is taking place (Experiments IIIC and IIICd in Table 3 were performed with DI water, and Part A and Part B RegenOx™, and without soil). The pH of all the samples containing oxidant increased during the test period.

Soil 2 had high oxidant demand, an average of 88.9 g/kg in the 18-g/L experiments and an average of 267 g/kg in the 54-g/L experiments on day 10. The results of the control experiments were also moderate at 53.3 g/L indicating that auto-decomposition of RegenOx™ is taking place (Experiments IIIC and IIICd of Table 3 were performed with DI water, and Part A and Part B RegenOx™, and without soil). The pH of all the samples with oxidant increased during the test period.

For Soil 1, the removal efficiency for benzene ranged from 46 to 76% with Regen-Ox. The removal efficiency for total VOCs ranged from 37 to 56%. The removal efficiency for benzo(a)pyrene could not be calculated as the initial soil samples could not detect benzo(a)pyrene at a lower detection limit due to interferences. The initial soil samples were analyzed by Lancaster Laboratories. The removal efficiency for SVOCs ranged from 88 to 90%.

For Soil 2, the removal efficiency for benzene ranged from 76 to 82% with Regen-Ox. The removal efficiency for total VOCs ranged from 18 to 30%. Results from the initial soil samples analyzed by Lancaster Laboratories were used to compare post-treatment results. The removal efficiency for SVOCs ranged from 41 to 42%. Benzo(a)pyrene was not detected above the method detection limit of 1,200 ug/Kg in the initial soil sample. Consequently, the removal efficiency of benzo(a)pyrene is not calculated. However, post-treatment results show that Regen-Ox was able to reduce the benzo(a)pyrene concentrations below 500 ug/Kg.

Tables 18 and 19 summarize the results of the chemical oxidation jar tests for the two soil samples.

3.5 Column Tests (Task 4)

Based on the higher destruction efficiency achieved using the CFR treatment, column experiments were conducted on one six-inch core from each soil. The oxidant solution, 15% peroxide with 5 g/L of ferrous sulfate at pH 3, was injected in an upflow mode through the soil. The effluent liquid was collected and analyzed on days 5, 14, and 21. The soil in the core and the gas generated were analyzed on day 21. The soil results are shown in Table 20, the water results are shown in Table 21, and the gas results are shown in Table 22.

Soil 1 had low permeability and the solution would not flow through the soil. The column experiment for this soil was stopped on day 14 with no effluent being collected or tested.

Soil 2 flow was adequate. The solution flowed through the soil for 22 days with an average flow rate of 0.065 mL/min. The gas generated was collected for the duration of the test. 13,022 mL of gas was collected in all. Samples of the effluent were taken on days 5, 14, and 21 with sampling continuing until enough was collected for analysis.

Total target VOCs in the column effluent at Day 5 and Day 14 were measured at 178.4 and 294.4 ppb. Benzene was detected at a concentration of 33 ppb on Day 5 and at 43 ppb on Day 14. Total Target SVOCs were detected at 400.4 and 1,366 ppb on Day 5 and Day 14, respectively. The total target VOCs is the sum of VOCs detected minus acetone and 2-butanone. These compounds are degradation products of natural organic matter such as peat. The residual peroxide concentration in the effluent increased from 0.658 g/L on Day 5 to 1.31 g/L on Day 21, indicating that the demand for oxidant was diminishing over time as the contaminants were being oxidized.

The results of the soil analyses at the end of the column test indicate that there was a 77% reduction in total VOCs and 21% reduction in benzene. The reduction in benzene is low compared to that observed in the jar test (93%) with CFR for Soil 2. This indicates that redosing of the CFR during field application may be necessary in order to achieve higher destruction efficiency of the benzene. There was a 74 % decrease in total VOC concentrations in the column soil as compared to the initial results. The concentrations of 1-methylnaphthalene and 2-methylnaphthalene in the column soil were decreased by 57 % and 79 % respectively when compared to the initial concentrations found in the soil.

Table 22 shows the estimated mass of VOCs collected in the soil gas sample from the column test. The table shows that approximately 413 ug of VOCs were lost in the gas generated from the ISCO reaction. This is a negligible amount of VOCs in the gas phase (0.0013%) as compared to the initial mass of VOCs in the column (31,199 ug). The soil mass in the column was 219 g and the initial VOC concentration in the soil was 142,460 ug/kg.

Total lead decreased from an average of 599 mg/kg to 149 mg/kg and TCLP lead decreased from an average of 2.88 mg/L to 0.406 mg/L after treatment. TCLP benzene showed a slight decrease from an average of 11 μg/L to 9.6 μg/L in the soil after treatment.

4.0 Conclusions

- The estimated soil oxidant demand (SOD) was 781 g/Kg with 15% CFR and 1,303 g/Kg with 25% CFR. The estimated SOD was 85.3 g/kg and 162.5 g/kg with 20 and 40 g/L activated persulfate, respectively. The estimated SOD was 92.5 g/kg and 281 g/kg with 18 and 54 g/L Regen-Ox, respectively. The oxidant demand for CFR is high due to its high reactivity with other constituents in the fill material.
- Although the SOD was relatively high for CFR, CFR achieved a high removal efficiency of the COCs in Soil 2. Total VOCs were decreased by more than 77% in the column test.
- CFR is most effective in reducing the mass of petroleum hydrocarbons in the shortest time frame. CFR treatment also increased availability of some compounds for oxidation through desorption.
- In batch tests, Soil 2 showed a moderate decrease in COC concentrations with activated persulfate treatment. Removal efficiency for total VOCs ranged from 2 to 48%. The removal efficiency for SVOCs was 46%. The removal efficiency for SVOCs ranged from 86 to 88% with activated persulfate in Soil 1.
- In batch tests for Soil 1, the removal efficiency for total VOCs ranged from 37 to 56% using Regen-Ox. The removal efficiency for SVOCs ranged from 88 to 90%. For Soil 2, the removal efficiency for total VOCs ranged from 18 to 30% and the removal efficiency for SVOCs ranged from 41 to 42%.

Table 1: SOD and Degradation of COC's Using CFR Test Conditions (Task 1)

ID	water to dry soil ratio	concentration of hydrogen peroxide	amount of ferrous sulfate	initial pH of solution	test length
IA & IAd	5:1	40 g/L	5 g/L	3	24 hours
IB & IBd	5:1	80 g/L	9 g/L	3	24 hours
IC & ICd	no soil	80 g/L	9 g/L	3	24 hours
ID & IDd	5:1	none	none	3	24 hours

Table 2: SOD and Degradation of COC's Using Iron Catalyzed Persulfate Test Conditions (Task 2)

ID	water to dry soil ratio	concentration of persulfate	amount of iron (II)	test length
IIA & IIAd	5:1	20 g/L	300 mg/L	10 days
IIB & IIBd	5:1	40 g/L	400 mg/L	10 days
IIC & IICd	no soil	40 g/L	400 mg/L	10 days
IID & IIDd	5:1	none	none	10 days

Table 3: SOD and Degradation of COC's Using RegenOx™ Test Conditions (Task 3)

ID	water to dry soil ratio	amount of RegenOx		test length
		Part A	Part B	
IIIA & IIIAd	5:1	8 mL/L	10 g/L	10 days
IIIB & IIIBd	5:1	24 g/L	30 g/L	10 days
IIIC & IIICd	no soil	24 g/L	30 g/L	10 days
IIID & IIIDd	5:1	none	none	10 days

Table 4: Summary of Analytical Instruments and Methods Used in the Study

Parameters	Instruments	Analysis methods
pH	Accumet Model AR20 pH/Ion meter or equivalent	Solution pH (EPA 150.1); Soil pH (SW846 9045C)
ORP, DO, and specific conductance	Orion Research EA-940 for ORP, YSI-5000 for DO, Accumet Model 50 for specific conductance	Standard methods for water and soil
grain size analysis	ASTM Sieves	ASTM method D-422
persulfate	Spectronic Genesys-5 Spectrophotometer	Colorimetric methods
hydrogen peroxide	Laboratory glassware (Beaker, Buret)	Titrimetric-colorimetric method
VOCs (soil and water)	GC/MS	SW846 8260B
VOCs (gas)	GC/MS	TO-14A
total organic carbon	Tekmar Dohrmann, Apollo-9000	SM 5310B/EPA 415.1 for water, SW846 9060 for soil
SVOCs (PAHs in soil and water)	GC/MS	SW846 8270C

Table 5: Initial Characterization of the Site Soil Samples

	SA75376-03 0402-inisoil1	SA75376-04 0402-inisoil1d	SA75376-05 0402-inisoil2	SA75376-06 0402-inisoil2d	SA78412-76 0613-soil-1	SA78412-77 0613-soil-2
	S2249RG2		S1016RC1		retest of soils	
SW 846 8260B (µg/kg dry)						
Benzene	276,000	187,000	4,770	2,780	N/A	N/A
n-Butylbenzene	10,200	7,690	5,840	908	N/A	N/A
sec-Butylbenzene	5,910	4,820	2,330	<202	N/A	N/A
tert-Butylbenzene	1,030	<178	<153	<151	N/A	N/A
Ethylbenzene	43,600	31,000	3,460	1,650	N/A	N/A
Isopropylbenzene	9,500	7,690	6,010	1,110	N/A	N/A
4-Isopropyltoluene	7,870	6,300	3,140	<202	N/A	N/A
Naphthalene	71,200	55,400	8,010	7,740	N/A	N/A
n-Propylbenzene	17,200	12,800	12,800	2,300	N/A	N/A
Toluene	51,200	37,600	1,580	<269	N/A	N/A
1,2,4-Trimethylbenzene	143,000	107,000	72,100	29,600	N/A	N/A
1,3,5-Trimethylbenzene	59,500	42,100	35,800	9,390	N/A	N/A
m,p-Xylene	199,000	139,000	46,800	22,100	N/A	N/A
o-Xylene	74,000	56,000	2,920	2,690	N/A	N/A
SW846 1311/8260B (µg/L)						
TCLP Benzene	2,140	3,380	8.6	13.4	N/A	N/A
SW846 8270C (µg/kg dry)						
Acenaphthene	<402	<415	<40.7	<37.9	130 J	<120
Benzo (a) pyrene	<568	<586	<57.6	<53.5	<120	<140
Fluorene	4,190	3,040	<40.7	<37.9	180 J	<130
1-Methylnaphthalene	25,000	18,100	2,600	2,600	16,000	<100
2-Methylnaphthalene	38,500	28,000	4,570	4,580	26,000	<100
Phenanthrene	11,300	8,050	<77.9	<72.5	180 J	<150
Pyrene	4,350	2,940	197	221	140 J	<140
MOD SW846 8270C (µg/kg dry)						
Tetraethyl lead	<6,630	<6,840	<655	<626	N/A	N/A
SW846 1311/6010B (mg/L)						
TCLP Lead	0.808	0.516	2.12	3.64	N/A	N/A
SW846 6010B (mg/kg dry)						
Lead	618	685	247	950	N/A	N/A
SW846 9060 (mg/kg)						
Total Organic Carbon	98,100	61,000	45,400	55,300	N/A	N/A
Wet Chemistry Parameters						
% Solids	70.8	69.0	76.1	76.5	N/A	N/A
Grain size, percent retained						
Fractional % Sieve #4 (>4750µm)	0.00	0.00	5.66	16.0	N/A	N/A
Fractional % Sieve #10 (4750-2000µm)	4.69	1.72	12.8	29.4	N/A	N/A
Fractional % Sieve #20 (2000-850µm)	18.6	8.62	19.6	21.5	N/A	N/A
Fractional % Sieve #40 (850-425µm)	27.8	17.2	15.7	12.9	N/A	N/A
Fractional % Sieve #60 (425-250µm)	22.9	14.7	9.55	6.65	N/A	N/A
Fractional % Sieve #100 (250-150µm)	11.0	6.90	11.7	5.87	N/A	N/A
Fractional % Sieve #200 (150-75µm)	8.48	27.6	4.69	5.68	N/A	N/A
Fractional % Sieve #230 (less than 75µm)	6.50	23.3	20.4	1.96	N/A	N/A

Table 6: SOD for CFR Results Soil 1 (Task 1)

		Hour 2		Hour 4		Hour 24	
ID	initial	result	SOD	result	SOD	result	SOD
IA	150	0.0178	783 g/kg	1.34	776 g/kg	0.425	780 g/kg
IAd	150	0.0017	783 g/kg	4.47	759 g/kg	0.163	782 g/kg
IB	250	5.94	1,273 g/kg	0.340	1,303 g/kg	0.178	1,303 g/kg
IBd	250	12.0	1,242 g/kg	0.987	1,299 g/kg	0.340	1,303 g/kg
IC	250	0.178	250 g/L	0.0178	250 g/L	0.0017	250 g/L
ICd	250	0.0017	250 g/L	0.0178	250 g/L	0.0178	250 g/L
ID	none	0.0089	N/A	0.0008	N/A	0.0010	N/A
IDd	none	0.0008	N/A	0.0089	N/A	0.0017	N/A

Table 7: SOD for CFR Results Soil 2 (Task 1)

		Hour 2		Hour 4		Hour 24	
ID	initial	result	SOD	result	SOD	result	SOD
IA	150	0.130	779 g/kg	0.341	778 g/kg	0.261	778 g/kg
IAd	150	0.746	776 g/kg	0.568	777 g/kg	0.277	778 g/kg
IB	250	0.180	1,298 g/kg	0.196	1,298 g/kg	0.309	1,298 g/kg
IBd	250	0.228	1,298 g/kg	0.309	1,298 g/kg	0.244	1,298 g/kg
IC	250	0.178	250 g/L	0.0017	250 g/L	0.0178	250 g/L
ICd	250	0.0017	250 g/L	0.0178	250 g/L	0.0017	250 g/L
ID	none	0.0178	N/A	0.0008	N/A	0.0008	N/A
IDd	none	0.0008	N/A	0.0008	N/A	0.0089	N/A

Table 8: Degradation Using CFR Results Soil 1 (Task 1)

	Initial Characterization		Hour 24 Solid					
	SA75376-03	SA75376-04	SA78412-53	SA78412-54	SA78412-55	SA78412-56	SA78412-57	SA78412-58
	0402-inisoil1	0402-inisoil1d	0514-IA-s-24	0514-IAd-s-24	0514-IB-s-24	0514-IBd-s-24	0514-ID-s-24	0514-IDd-s-24
	S2249RG2		soil 1 and DI water 15% hydrogen peroxide 5 g/L ferrous sulfate at pH 3		soil 1 and DI water 25% hydrogen peroxide 9 g/L ferrous sulfate at pH 3		soil 1 and DI water at pH 3	
SW 846 8260B (µg/kg)								
Benzene	276,000	187,000	6,100	4,300	3,100	8,400	6,300	3,500
n-Butylbenzene	10,200	7,690	4,300	4,100	3,500	4,900	4,200	4,600
sec-Butylbenzene	5,910	4,820	960	1,300 J	900 J	1,400 J	1,200 J	1,100 J
tert-Butylbenzene	1,030	<178	<390	<370	<340	<360	<380	<130
Ethylbenzene	43,600	31,000	5,400	4,000	3,000	6,900	6,200	4,200
Isopropylbenzene	9,500	7,690	1,300	1,700 J	950 J	2,000 J	1,800 J	1,300 J
4-Isopropyltoluene	7,870	6,300	1,400	2,100 J	1,500 J	2,000 J	1,900 J	1,600 J
Naphthalene	71,200	55,400	8,000	9,900	5,100	13,000	10,000	6,100
n-Propylbenzene	17,200	12,800	3,400	2,800	2,200	3,900	3,600	3,100
Toluene	51,200	37,600	3,100	2,000	1,400 J	3,900 J	3,400	2,100
1,2,4-Trimethylbenzene	143,000	107,000	28,000	18,000	16,000	32,000	27,000	24,000
1,3,5-Trimethylbenzene	59,500	42,100	13,000	16,000	12,000	19,000	16,000	14,000
m,p-Xylene	199,000	139,000	22,000	15,000	10,000	28,000	24,000	16,000
o-Xylene	74,000	56,000	11,000	15,000	8,600	19,000	16,000	9,900
SW846 8270C (µg/kg)								
Acenaphthene	<402	<415	2,100	2,500 J	1,500	3,300 J	4,200 J	2,500 J
Anthracene	<502	<519	2,200	2,300 J	1,300 J	3,400 J	4,500 J	2,600 J
Benzo(a)anthracene	<1070	<1100	1,700	1,500 J	1,200 J	2,800 J	3,100 J	1,900 J
Benzo(a)pyrene	<568	<586	2,300	1,500 J	1,200 J	3,300 J	3,200 J	2,100 J
Benzo(b)fluoranthene	<2210	<2280	1,800	1,300 J	980 J	2,800 J	2,300 J	1,500 J
Benzo(g,h,i)perylene	<467	<482	3,500	2,200	1,900 J	5,300	4,100	2,600 J
Bis(2-ethylhexyl)phthalate	<3180	<3290	<720	850	<500	<1,500	<1,700	<650
Chrysene	<236	<244	3,000	3,100	2,100	4,600	4,800 J	3,000 J
Dibenzo(a,h)anthracene	<266	<275	960	710 J	650 J	1,600 J	1,400 J	740 J
Dibenzofuran	<201	<207	1,200	1,500 J	810 J	1,900 J	2,400 J	1,400 J
Fluoranthene	<402	<415	2,000	2,200 J	1,400 J	3,200 J	3,500 J	1,900 J
Fluorene	4,190	3,040	3,700	4,200	2,500	5,900	7,000	4,100
Indeno(1,2,3-cd)pyrene	<769	<793	1,000	640 J	560 J	1,400 J	<1,400	780
1-Methylnaphthalene	25,000	18,100	22,000	25,000	15,000	34,000	43,000	26,000
2-Methylnaphthalene	38,500	28,000	35,000	28,000	18,000	52,000	53,000	29,000
Phenanthrene	11,300	8,050	11,000	13,000	7,600	18,000	21,000	12,000
Pyrene	4,350	2,940	4,600	4,900	3,300	7,500	8,200	4,800

Table 9: Degradation Using CFR Results Soil 2 (Task 1)

	Initial Characterization		Hour 24 Solid					
	SA75376-05	SA75376-06	SA77616-91	SA77616-92	SA77616-93	SA77616-94	SA77616-95	SA77616-96
	0402-inisoil2	0402-inisoil2d	0509-IA-s-24	0509-IAd-s-24	0509-IB-s-24	0509-IBd-s-24	0509-ID-s-24	0509-IDd-s-24
	S1016RC1		soil 2 and DI water 15% hydrogen peroxide at pH 3 5 g/L ferrous sulfate at pH 3		soil 2 and DI water 25% hydrogen peroxide at pH 3 9 g/L ferrous sulfate at pH 3		soil 2 and DI water at pH 3	
SW 846 8260B (µg/kg)								
Benzene	4,770	2,780	210 J	300 J	270 J	290 J	930 J	440 J
n-Butylbenzene	5,840	908	1,500	2,100	1,600	2,300	7,600	6,300
sec-Butylbenzene	2,330	<202	<23	360 J	280 J	410 J	<110	<84
1,2-Dichloropropane	<153	<151	240 J	<29	300 J	<30	<150	<110
Ethylbenzene	3,460	1,650	230 J	490 J	450 J	770	1,800 J	42,000
Isopropylbenzene	6,010	1,110	290 J	650	490 J	860	2,700	1,300 J
4-Isopropyltoluene	3,140	<202	<17	630	<16	710	<76	<59
Naphthalene	8,010	7,740	1,100	1,600	1,200	1,800	7,000	4,400
n-Propylbenzene	12,800	2,300	<26	1,300	1,000	1,700	5,300	2,600
Toluene	1,580	<269	<17	120 J	110 J	130 J	<76	<59
1,2,4-Trimethylbenzene	72,100	29,600	9,800	16,000	11,000	17,000	73,000	57,000
1,3,5-Trimethylbenzene	35,800	9,390	4,600	7,400	5,100	7,700	34,000	30,000
m,p-Xylene	46,800	22,100	5,100	10,000	7,600	12,000	53,000	35,000
o-Xylene	2,920	2,690	570	1,500	990	1,500	4,700	3,800

SW846 8270C (µg/kg)

Benzo (a) pyrene	<57.6	<53.5	<130	<130	<130	<130	<250	430
Benzo(g,h,i)perylene	<47.4	<44.1	<120	<120	<120	<120	250	240
Chrysene	<23.9	<22.3	200	250	170	180	500	460
Diethylphthalate	<54.5	<50.7	<130	<120	<130	<120	<240	330
2,4-Dimethylphenol	<77.9	<72.5	870	1,100	980	990	1,900	1,900
Fluorene	<40.7	<37.9	<120	<120	<120	<120	270	240
1-Methylnaphthalene	2,600	2,600	1,500	2,500	1,600	1,700	7,400	6,800
2-Methylnaphthalene	4,570	4,580	2,800	4,500	3,100	3,300	13,000	11,000
2-Methylphenol	<71.3	<66.3	540	800	640	580	870	880
3&4-Methylphenol	<40.7	<37.9	710	600	680	630	1,100	1,100
Phenanthrene	<77.9	<72.5	<140	170	140	<130	380	350
Phenol	<34.0	<31.6	250	240	290	220	480	390
Pyrene	197	221	190	200	170	170	570	530

Table 10: SOD for Iron Catalyzed Persulfate Results Soil 1 (Task 2)

		Day 1		Day 4		Day 10	
ID	initial	result	SOD	result	SOD	result	SOD
IIA	20	8.18	61.7 g/kg	4.80	79.3 g/kg	2.87	89.4 g/kg
IIAd	20	9.48	54.9 g/kg	8.21	61.5 g/kg	4.44	81.2 g/kg
IIB	40	27.0	67.9 g/kg	15.9	126 g/kg	9.11	161 g/kg
IIBd	40	21.0	99.0 g/kg	13.8	137 g/kg	8.63	164 g/kg
IIC	40	30.6	9.41 g/L	26.5	13.5 g/L	22.6	17.4 g/L
IICd	40	31.1	8.91 g/L	26.5	13.5 g/L	18.6	21.4 g/L
IID	none	-0.0307	N/A	-0.0371	N/A	-0.0012	N/A
IIDd	none	-0.0320	N/A	-0.0363	N/A	-0.0038	N/A

Table 11: SOD for Iron Catalyzed Persulfate Results Soil 2 (Task 2)

		Day 1		Day 4		Day 10	
ID	initial	result	SOD	result	SOD	result	SOD
IIA	20	12.3	38.4 g/kg	8.13	58.8 g/kg	6.04	69.2 g/kg
IIAd	20	13.0	34.7 g/kg	9.38	52.7 g/kg	5.92	69.8 g/kg
IIB	40	29.4	52.5 g/kg	23.8	80.3 g/kg	18.83	105 g/kg
IIBd	40	28.8	55.5 g/kg	23.4	82.6 g/kg	18.64	106 g/kg
IIC	40	32.9	7.15 g/L	27.2	12.8 g/L	22.2	17.8 g/L
IICd	40	32.5	7.51 g/L	27.6	12.4 g/L	21.0	19.0 g/L
IID	none	0.0208	N/A	-0.0051	N/A	-0.0154	N/A
IIDd	none	0.0183	N/A	-0.0051	N/A	-0.0154	N/A

Table 12: Degradation Using Iron Catalyzed Persulfate Results Soil 1 (Task 2)

	Initial Characterization		Day 10 Solid					
	SA75376-03	SA75376-04	SA75376-57	SA75376-58	SA75376-59	SA75376-60	SA75376-61	SA75376-62
	0402-inisoil1	0402-inisoil1d	0417-IIA-s	0417-IIAd-s	0417-IIB-s	0417-IIBd-s	0417-IID-s	0417-IIDd-s
	S2249RG2		soil 1 and DI water 20 g/L persulfate 300 mg/L iron		soil 1 and DI water 40 g/L persulfate 400 mg/L iron		soil 1 and DI water only	
SW 846 8260B (µg/kg)								
Benzene	276,000	187,000	88,100	113,000	48,200	30,700	164,000	73,200
n-Butylbenzene	10,200	7,690	10,300	6,590	6,970	5,800	10,100	6,630
sec-Butylbenzene	5,910	4,820	7,480	7,610	7,690	6,510	9,530	6,850
tert-Butylbenzene	1,030	<178	1,320	969	<137	735	1,340	718
Chloroethane	<413	<436	<263	<284	<335	611	<297	<259
Chloromethane	<169	<178	<108	<116	989	1,050	<121	<106
Ethylbenzene	43,600	31,000	25,700	24,000	17,200	12,500	46,500	23,300
Isopropylbenzene	9,500	7,690	<156	<168	<198	<147	<175	<153
4-Isopropyltoluene	7,870	6,300	5,710	5,390	4,170	4,030	6,980	4,380
Methylene chloride	<901	<951	754	801	1,160	565	904	<565
Naphthalene	71,200	55,400	58,300	60,400	60,200	47,200	84,700	52,500
n-Propylbenzene	17,200	12,800	16,400	16,000	16,300	14,000	28,200	16,700
Toluene	51,200	37,600	20,100	24,600	9,830	5,380	41,300	17,600
1,2,4-Trimethylbenzene	143,000	107,000	64,200	66,000	52,000	38,600	147,000	82,300
1,3,5-Trimethylbenzene	59,500	42,100	27,900	31,100	20,700	14,900	58,400	32,500
m,p-Xylene	199,000	139,000	104,000	110,000	55,400	36,700	216,000	106,000
o-Xylene	74,000	56,000	39,100	42,600	21,700	15,000	85,800	43,900
SW846 8270C (µg/kg)								
Benzo(a)pyrene	<568	<586	<5,170	<5,420	<6,230	<5,090	<5,980	<5,100
Fluorene	4,190	3,040	<3,660	<3,840	<4,410	<3,610	<4,240	<3,610
1-Methylnaphthalene	25,000	18,100	52,700	45,400	42,300	63,700	32,100	68,600
2-Methylnaphthalene	38,500	28,000	22,600	18,200	<4,030	44,800	<3,860	49,300
Phenanthrene	11,300	8,050	<7,000	<7,340	<8,440	<6,900	<8,100	<6,910
Pyrene	4,350	2,940	<10,700	<11,200	<12,900	<10,600	<12,400	<10,600

Table 13: Degradation Using Iron Catalyzed Persulfate Results Soil 2 (Task 2)

	Initial Characterization		Day 10 Solid					
	SA75376-05	SA75376-06	SA77616-09	SA77616-10	SA77616-11	SA77616-12	SA77616-13	SA77616-14
	0402-inisoil2	0402-inisoil2d	0424-IIA-s	0424-IIAd-s	0424-IIB-s	0424-IIBd-s	0424-IID-s	0424-IIDd-s
	S1016RC1		soil 2 and DI water 20 g/L persulfate 300 mg/L iron		soil 2 and DI water 40 g/L persulfate 400 mg/L iron		soil 2 and DI water only	
SW 846 8260B (µg/kg)								
Benzene	4,770	2,780	2,000	899	1,120	1,350	3,700	3,780
n-Butylbenzene	5,840	908	3,120	5,100	2,970	3,580	5,050	5,570
sec-Butylbenzene	2,330	<202	1,270	1,990	1,180	1,560	2,230	2,170
Ethylbenzene	3,460	1,650	2,100	2,460	1,300	1,500	3,720	5,290
Isopropylbenzene	6,010	1,110	2,390	3,520	1,660	1,910	4,780	4,780
4-Isopropyltoluene	3,140	<202	1,840	2,730	1,550	1,960	3,240	2,790
Naphthalene	8,010	7,740	4,230	13,000	4,630	8,120	8,760	11,500
n-Propylbenzene	12,800	2,300	4,990	7,710	3,870	4,470	9,730	10,400
Toluene	1,580	<269	1,050	808	622	790	1,470	1,630
1,2,4-Trimethylbenzene	72,100	29,600	39,000	79,700	24,700	37,000	78,000	99,700
1,3,5-Trimethylbenzene	35,800	9,390	16,600	26,300	10,000	13,200	32,300	34,600
m,p-Xylene	46,800	22,100	22,600	32,800	9,340	11,000	50,300	67,800
o-Xylene	2,920	2,690	2,190	2,810	829	1,110	4,070	7,400
SW846 8270C (µg/kg)								
Benzo (a) pyrene	<57.6	<53.5	<13,800	<13,100	<13,200	<13,700	<16,200	<13,700
1-Methylnaphthalene	2,600	2,600	<134	<128	<129	<133	<157	<133
2-Methylnaphthalene	4,570	4,580	<8,890	<8,490	<8,560	<8,840	<10,400	<8,830
Pyrene	197	221	<28,500	<27,200	<27,400	<28,300	<33,500	<28,300

Table 14: SOD for RegenOx™ Results Soil 1 (Task 3)

		Day 1		Day 4		Day 10	
ID	initial	result	SOD	result	SOD	result	SOD
IIIA	18	0.221	92.8 g/kg	0.228	92.7 g/kg	0.261	92.6 g/kg
IIIAd	18	0.255	92.6 g/kg	0.325	92.2 g/kg	0.293	92.4 g/kg
IIIB	54	0.221	281 g/kg	0.228	281 g/kg	0.115	281 g/kg
IIIBd	54	0.187	281 g/kg	0.180	281 g/kg	0.147	281 g/kg
IIIC	54	3.57	50.4 g/L	1.72	52.3 g/L	0.989	53.0 g/L
IIICd	54	3.72	50.3 g/L	1.18	52.8 g/L	0.390	53.6 g/L
IIID	none	0.0503	N/A	0.0089	N/A	0.0089	N/A
IIIDd	none	0.0333	N/A	0.0251	N/A	0.0332	N/A

Table 15: SOD for RegenOx™ Results Soil 2 (Task 3)

		Day 1		Day 4		Day 10	
ID	initial	result	SOD	result	SOD	result	SOD
IIIA	18	0.293	87.8 g/kg	0.131	88.6 g/kg	0.136	88.6 g/kg
IIIAd	18	0.390	87.3 g/kg	0.0664	88.9 g/kg	0.0412	89.1 g/kg
IIIB	54	0.584	265 g/kg	0.196	267 g/kg	0.0728	267 g/kg
IIIBd	54	0.749	264 g/kg	0.261	266 g/kg	0.0728	267 g/kg
IIIC	54	0.0146	54.0 g/L	1.75	52.3 g/L	0.651	53.3 g/L
IIICd	54	0.0178	54.0 g/L	1.75	52.3 g/L	0.658	53.3 g/L
IIID	none	0.0008	N/A	0.0008	N/A	0.0048	N/A
IIIDd	none	-0.0024	N/A	0.0089	N/A	0.0031	N/A

Table 16: Degradation Using RegenOx™ Results Soil 1 (Task 3)

	Initial Characterization		Day 10 Solid					
	SA75376-03	SA75376-04	SA77616-37	SA77616-38	SA77616-39	SA77616-40	SA77616-41	SA77616-42
	0402-inisoil1	0402-inisoil1d	0501-IIIA-s	0501-IIIAd-s	0501-IIIB-s	0501-IIIBd-s	0501-IIID-s	0501-IIIDd-s
	S2249RG2		soil 1 and DI water 18 g/L RegenOx		soil 1 and DI water 54 g/L RegenOx		soil 1 and DI water only	
SW 846 8260B (µg/kg)								
Benzene	276,000	187,000	73,900	174,000	65,600	45,000	52,300	35,300
n-Butylbenzene	10,200	7,690	3,360	7,830	5,250	5,050	7,180	4,400
sec-Butylbenzene	5,910	4,820	2,520	4,650	3,180	3,220	4,300	3,010
tert-Butylbenzene	1,030	<178	<138	932	<144	719	841	<121
Ethylbenzene	43,600	31,000	15,100	33,300	20,200	15,700	20,800	14,100
Isopropylbenzene	9,500	7,690	4,040	7,870	5,380	4,890	6,150	4,370
4-Isopropyltoluene	7,870	6,300	3,250	5,970	4,320	4,300	5,450	3,840
Naphthalene	71,200	55,400	33,000	60,500	44,200	42,600	55,100	43,600
n-Propylbenzene	17,200	12,800	6,020	13,500	9,230	8,010	11,100	7,290
Toluene	51,200	37,600	20,900	41,900	20,000	15,000	18,000	13,200
1,2,4-Trimethylbenzene	143,000	107,000	47,600	105,000	69,800	61,700	84,500	60,100
1,3,5-Trimethylbenzene	59,500	42,100	21,800	44,300	30,800	27,700	37,000	27,600
m,p-Xylene	199,000	139,000	73,700	149,000	84,700	68,000	88,600	64,000
o-Xylene	74,000	56,000	30,200	60,200	40,200	34,900	42,200	33,400
SW846 8270C (µg/kg)								
Benzo(a)pyrene	<568	<586	<18,800	<16,400	<18,200	<18,900	<16,500	<16,800
Fluorene	4,190	3,040	<13,300	<11,600	<12,900	<13,400	<11,700	<11,900
1-Methylnaphthalene	25,000	18,100	<183	119,000	75,200	74,700	53,500	<164
2-Methylnaphthalene	38,500	28,000	<12,100	<10,600	<11,800	<12,200	<10,700	<10,900
Phenanthrene	11,300	8,050	<25,400	<22,300	<24,600	<25,600	<22,300	<22,800
Pyrene	4,350	2,940	<38,800	<34,000	<37,700	<39,100	<34,200	<34,900

Table 17: Degradation Using RegenOx™ Results Soil 2 (Task 3)

	Initial Characterization		Day 10 Solid					
	SA75376-05	SA75376-06	SA78412-67	SA78412-68	SA78412-69	SA78412-70	SA78412-71	SA78412-72
	0402-inisoil2	0402-inisoil2d	0515-IIIA-s	0515-IIIAd-s	0515-IIIB-s	0515-IIIBd-s	0515-IIID-s	0515-IIIDd-s
	S1016RC1		soil 2 and DI water 18 g/L RegenOx		soil 2 and DI water 54 g/L RegenOx		soil 2 and DI water only	
SW 846 8260B (µg/kg)								
Benzene	4,770	2,780	560	780 J	<290	1,500	570 J	840 J
n-Butylbenzene	5,840	908	4,100	5,100	3,000	7,900	5,400	5,800
sec-Butylbenzene	2,330	<202	720	1,000 J	470 J	1,500 J	870 J	950 J
1,2-Dichloropropane	<153	<151	<94	1,100	620 J	<97	1,200	<92
Ethylbenzene	3,460	1,650	1,600	1,300	590 J	3,400 J	650	1,500 J
Isopropylbenzene	6,010	1,110	1,600	2,700	940	3,600 J	1,700	1,900 J
4-Isopropyltoluene	3,140	<202	1,200	1,700 J	1,100	2,400 J	2,000	1,900
Naphthalene	8,010	7,740	3,400	3,400	1,900	7,200	2,700	4,600
n-Propylbenzene	12,800	2,300	3,100	5,000	1,900	7,200	3,300	3,600
Toluene	1,580	<269	<48	<48	<53	570	<53	<48
1,2,4-Trimethylbenzene	72,100	29,600	37,000	38,000	24,000	68,000	36,000	51,000
1,3,5-Trimethylbenzene	35,800	9,390	16,000	19,000	13,000	29,000	23,000	23,000
m,p-Xylene	46,800	22,100	26,000	25,000	14,000	53,000	19,000	22,000
o-Xylene	2,920	2,690	3,600	1,800	1,600	8,700 J	2,300	5,100
SW846 8270C (µg/kg)								
Acenaphthene	<40.7	<37.9	<380	360	<360	<350	<510	<310
Anthracene	<50.9	<47.4	<430	440	<420	<400	<590	<350
Benzo(a)anthracene	<108	<101	<440	<380	<420	<400	<590	570
Benzo (a) pyrene	<57.6	<53.5	<430	<380	<410	<400	<580	<350
Chrysene	<23.9	<22.3	500	660 J	510 J	490 J	670 J	570 J
Diethylphthalate	<54.5	<50.7	<410	<360	<400	<380	<560	560
2,4-Dimethylphenol	<77.9	<72.5	1,400	2,600 J	2,000	2,200	2,400	2,300
Fluorene	<40.7	<37.9	<400	550	<390	<370	<540	<330
1-Methylnaphthalene	2,600	2,600	7,100	12,000	8,100	7,800	9,000	8,800
2-Methylnaphthalene	4,570	4,580	12,000	21,000	14,000	15,000	15,000	15,000
2-Methylphenol	<71.3	<66.3	660	1,100 J	1,100 J	1,200 J	1,100 J	1,100 J
3&4-Methylphenol	<40.7	<37.9	960	1,400 J	1,200 J	1,200 J	1,500 J	1,200 J
Phenanthrene	<77.9	<72.5	580	860 J	620 J	440 J	890 J	500 J
Phenol	<34.0	<31.6	310	480 J	470 J	410 J	490 J	470 J
Pyrene	197	221	620	900 J	650 J	510 J	840 J	600 J

Table 18: Summary of chemical oxidation batch tests (Soil 1; S2249RG2)

	Concentration in Soil (ug/Kg)							
Target Constituent	Media	Initial	15% Hydrogen Peroxide	25% Hydrogen Peroxide	20 g/L Activated Persulfate	40 g/L Activated Persulfate	18 g/L Regen-OX	54 g/L Regen-OX
Benzene	Soil	231,500	4,750	5,750	100,550	39,450	123,950	55,300
Total VOCs		831,894	104,210	103,525	487,950	278,804	521,705	369,465
Benzo(a)pyrene		4,000	1,900	2,250	5,295	5,660	17,600	18,550
Total SVOCs		903,500	74,940	83,460	112,575	123,500	88,542	105,500

	Treatment Efficiency, %						
Target Constituent	Media	15% Hydrogen Peroxide	25% Hydrogen Peroxide	20 g/L Activated Persulfate	40 g/L Activated Persulfate	18 g/L Regen-OX	54 g/L Regen-OX
Benzene	Soil	98	98	57	83	46	76
Total VOCs		87	88	41	66	37	56
Benzo(a)pyrene		53	44	NA	NA	NA	NA
Total SVOCs		92	91	88	86	90	88

Table 19: Summary of chemical oxidation batch tests (Soil 2; S1016RC1)

	Concentration in Soil (ug/Kg)							
Target Constituent	**Media**	**Initial**	**15% Hydrogen Peroxide**	**25% Hydrogen Peroxide**	**20 g/L Activated Persulfate**	**40 g/L Activated Persulfate**	**18 g/L Regen-OX**	**54 g/L Regen-OX**
Benzene	Soil	3,775	260	280	1,450	1,235	670	895
Total VOCs		143,401	33,548	39,249	140,750	74,540	100,176	117,457
Benzo(a)pyrene		1,200 U	195	130	13,450	13,450	455	405
Total SVOCs		41,000	16,065	8,605	22,271	22,281	23,785	24,130

	Treatment Efficiency, %						
Target Constituent	**Media**	**15% Hydrogen Peroxide**	**25% Hydrogen Peroxide**	**20 g/L Activated Persulfate**	**40 g/L Activated Persulfate**	**18 g/L Regen-OX**	**54 g/L Regen-OX**
Benzene	Soil	93	93	62	67	82	76
Total VOCs		77	73	2	48	30	18
Benzo(a)pyrene		NA	NA	NA	NA	NA	NA
Total SVOCs		61	79	46	46	42	41

Table 20: Column Test Soil Results Soil 2; S1016RC1 (Task 4)

	Initial Characterization SA75376-05 0402-inisoil2 S1016RC1	Initial Characterization SA75376-06 0402-inisoil2d S1016RC1	Day 22 SA78412-83 0621-soil 2-Soil soil from column
SW 846 8260B (µg/kg)			
Acetone	<14,900	<14,800	11,000
Benzene	4,770	2,780	3,000
n-Butylbenzene	5,840	908	680 J
sec-Butylbenzene	2,330	<202	<94
Ethylbenzene	3,460	1,650	2,500
Isopropylbenzene	6,010	1,110	670 J
4-Isopropyltoluene	3,140	<202	<66
Naphthalene	8,010	7,740	1,200 J
n-Propylbenzene	12,800	2,300	870 J
Toluene	1,580	<269	1,500 J
1,2,4-Trimethylbenzene	72,100	29,600	6,500
1,3,5-Trimethylbenzene	35,800	9,390	2,000 J
m,p-Xylene	46,800	22,100	11,000
o-Xylene	2,920	2,690	2,600
SW846 8270C (µg/kg)			
Acenaphthene	<40.7	<37.9	490 J
Anthracene	<50.9	<47.4	620 J
Benzo(a)anthracene	<108	<101	240 J
Benzo (a) pyrene	<57.6	<53.5	210 J
Bis(2-ethylhexyl)phthalate	<323	<300	710 J
Chrysene	<23.9	<22.3	780 J
Dibenzofuran	<20.4	<19.0	480 J
2,4-Dimethylphenol	<77.9	<72.5	1,300 J
Fluoranthene	<40.7	<37.9	910 J
Fluorene	<40.7	<37.9	560 J
1-Methylnaphthalene	2,600	2,600	1,100 J
2-Methylnaphthalene	4,570	4,580	920 J
2-Methylphenol	<71.3	<66.3	1,000 J
3&4-Methylphenol	<40.7	<37.9	1,500 J
Phenanthrene	<77.9	<72.5	2,400
Phenol	<34.0	<31.6	640 J
Pyrene	197	221	810 J
SW846 1311/8260B (µg/L)			
TCLP Benzene	8.6	13.4	9.6
MOD SW846 8270C (µg/kg dry)			
Tetraethyl lead	<655	<626	<288
SW846 1311/6010B (mg/L)			
TCLP Lead	2.12	3.64	0.406
SW846 6010B (mg/kg dry)			
Lead	247	950	149

Table 21: Column Test Water Results Soil 2; S1016RC1 (Task 4)

	Day 5 SA78412-73, 74 0605-soil 2-IV	Day 14 SA78412-75, 78, 79 0612 - 0617	Day 21 SA78412-80, 81, 82 0619 - 0621
SW 846 8260B (µg/L)			
Acetone	6,000	8,600 E	9,300
Benzene	33 J	43	26 J
2-Butanone	340	470	570
Ethylbenzene	<3.3	22	16 J
Methylene chloride	12 J	<4.4	12
Toluene	<7.1	13	<7.1
1,2,4-Trimethylbenzene	26 J	40	30 J
1,3,5-Trimethylbenzene	10 J	15	10 J
m,p-Xylene	65	120	83
o-Xylene	22 J	37	27 J
SW846 8270C (µg/L)			
Acenaphthene	<6.6	74 J	33 J
Anthracene	<7.5	100 J	41 J
Benzo(a)anthracene	<7.4	32 J	<25
Benzo (a) pyrene	<7.8	30 J	<26
Benzo(b)fluoranthene	<12	29 J	<40
Benzo(k)fluoranthene	<8.8	17 J	<29
Bis(2-ethylhexyl)phthalate	<20	<36	51 J
Chrysene	<8.8	94 J	47 J
Dibenzofuran	<5.8	<10	28 J
2,4-Dimethylphenol	290	130 J	<80
Fluoranthene	<8.0	130 J	59 J
Fluorene	<6.7	71 J	36 J
1-Methylnaphthalene	<6.3	120 J	54 J
2-Methylnaphthalene	<6.6	50 J	<22
4-Methylphenol	<8.8	19 J	<29
Phenanthrene	<8.0	370	150 J
Pyrene	<7.1	100 J	54 J
Wet Chemistry Parameters			
Dissolved oxygen, mg/L	6.77	8.20	12.7
pH	3.99	3.03	2.40
ORP, mV	483.8	585.9	632.4
Conductivity, mS/cm	2.84	4.48	6.11
Peroxide, g/L	0.658	1.01	1.31

Table 22: Column Test Gas Results Soil 2 (Task 4)

total volume of gas generated during 22 day experiment was 13,022 mL	SA78412-84 0621-soil 2-Gas gas from column on day 22
Mod. EPA TO-14A__TO-14 A (ppbv)	
Benzene	744
Bromomethane	670
Ethylbenzene	682
4-Ethyltoluene	210
Methylene chloride	56.0
Toluene	830
1,2,4-Trimethylbenzene	490
1,3,5-Trimethylbenzene	164
m,p-Xylene	2,860
o-Xylene	714